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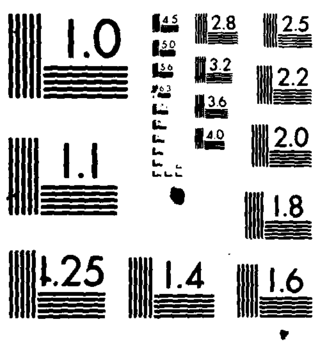

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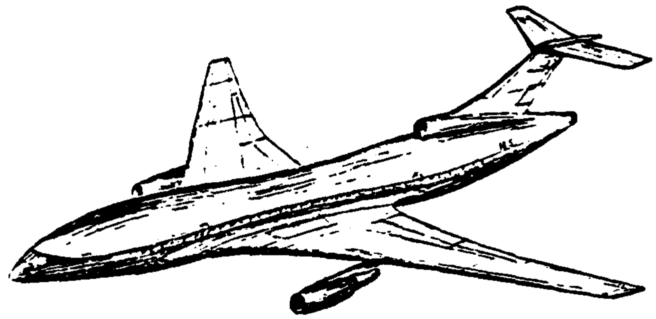
TRANSONIC FLUID DYNAMICS

Report TFD 81-03

H. Sobieczky

# SURFACE GENERATION FOR AERODYNAMIC APPLICATIONS



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This paper describes an analytical procedure to obtain the geometry of wing-body combinations, missiles, rotors and propellers, to be used in computational algorithms as well as for automated tool manufacturing wind tunnel models for flow-field analysis, with emphasis on parametrical shape

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variations needed in aerodynamic design and optimization procedures. Analytical shape definition allows for arbitrary surface coordinates generation to be combined with three-dimensional (flow space) grid generators. Present version of the code (E88-A) defines the wing along sections at constant span, with smooth deviations near the wing root section, which is projected onto the body surface. The body is defined by cross-section shapes based on superelliptic arcs, connecting analytic crown lines and planform projection curves. Wing sections are defined by an analytical blending between given root and central sections for the inner part of the wing, and the same between the central and tip section for the outer part of the wing. These three basic airfoils may be given as dense data from preceding two-dimensional design or as relatively few spline supports for an interpolation technique of suitably stretched ordinates in order to density airfoil data.

H. Sobieczky

DFVLR Institut für Theoretische Stroemungsmechanik

Goettingen, Germany

# SURFACE GENERATION

# FOR AERODYNAMIC APPLICATIONS

Contents:

## INTRODUCTION

This paper describes an analytical procedure to obtain the geometry of wing-body combinations, missiles, rotors and propellers, to be used in computational algorithms as well as for automated tool manufacturing wind tunnel models for flow-field analysis, with emphasis on parametrical shape variations needed in aerodynamic design and optimization procedures. Analytical shape definition allows for arbitrary surface coordinates generation to be combined with three-dimensional (flow space) grid generators. Present version of the code (E88-A) defines the wing along sections at constant span, with smooth deviations near the wing root section, which is projected onto the body surface. The body is defined by cross-section shapes based on superelliptic arcs, connecting analytic crown lines and planform projection curves. Wing sections are defined by an analytical blending between given root and central sections for the inner part of the wing, and the same between the central and tip section for the outer part of the wing. These three basic airfoils may be given as dense data from preceding two-dimensional design or as relatively few spline supports for an interpolation technique of suitably stretched ordinates in order to density airfoil data.

## CODE INPUT DESCRIPTION

### Basic airfoils

Three basic airfoils are used for section definition at any span station of the wing: A root section, a main section and a tip section are given. For each of these three sections a number of upper surface and a number of lower surface coordinates is given. Ordinates are then blown up to provide a suitable input for spline redistribution of all three airfoils with the same number of surface points, at equivalent arc length stations between leading and trailing edge.

Input for 3 basic airfoils:

a) Data for each (root, main, tip) section L = 1,2,3:

| | |
|---|---|
| $NU1_L$ | Number of upper surface support points (including L. E. point) |
| $NU1_L$ | Number of lower surface support points (including L. E. point) |
| $XDAT(N,1)_L$, $YDAT(N,1)_L$ | Upper surface supports, N = 1, NU1 |
| $XDAT(N,2)_L$, $YDAT(N,2)_L$ | Lower surface supports, N = 1, NL1 |

b) Data for redistributed sections

| | |
|---|---|
| NU<br>NL | Number of upper and lower surface redistributed coordinates. |
| CBLOW | Blow-up factor for spline redistribution. |

Wing or blade surface

The three basic sections with an equal number of points are placed at three span stations. Three thickness parameters allow for individual thickness variation. A weighted analytical blending in the two intervals between the three basic sections allows for section definition at each prescribed span station. Wing planform leading edge, trailing edge, section twist axis location, dihedral and amount of section twist is described along with the span locations by a Planform Definition Matrix.

Input for wing/blade generator

| | |
|---|---|
| S1, S2, S3 | Thickness reduction factors for 3 basic sections. |
| Y1, Y2, Y3 | Root, main, tip section span location. |
| E1 | Root section influence parameter (E1 > 0, higher influence on wing shape for larger E1). |
| F2, E2 | Main section influence parameters. (F2, E3 > 0, higher influence on wing shape for larger values). |

| | |
|---|---|
| F3 | Tip section influence parameter (F3 > 0, higher influence on wing shape for larger F3). |
| NE | Number of generated wing sections. |
| A(I,J) | Planform definition matrix using subroutine SHAPE (Q(J), J = 1, 10), Ref. (1) |
| I | 1 section distribution function |
| | 2 leading edge shape |
| | 3 trailing edge shape |
| | 4 section twist axis location: planform |
| | 5 section twist axis location: an/dihedral of wing |
| | 6 section twist in degrees |

Fuselage, rotor hub or centerbody surface

Nose and tail location define an interval where crown upper and lower lines are given, also the planform projection of the body and the vertical ordinate of this projection contour. These data form endpoints of superelliptic cross-section quarters, with exponents also given as functions of the x-station between nose and tail.

Input for body surface generation

| | |
|---|---|
| XNOSE<br>XTAIL | x-stations of body nose and tail |
| KE | Number of body cross-sections |
| AFG.<br>BFG.<br>EFG.<br>FFG. | Cross section x-stations: distribution by subroutine FORM (Ref. 1) with 4 input parameters |
| LE | Number of body surface points per half cross-section. |
| H1, H2 | Clustering parameters at lower (H1) and upper (H2) crown line, for points along cross section arc. Se H1, H2 = 2 for continuously curved cross section at crown lines. |
| Q, G1, G2 | Parameters for cross section definitions deviating significantly from elliptic sections. Usually Q = 1., G1 = G2 = 2. |

IF — Fuselage definition matrix F(I, J), I = IF lines read.

F(I, J) — Fuselage definition matrix, superposition of bumps/ramps/steps defined by subroutine BUSTER (F(I, 2), F(I, 3), .... F(I, 11), x, z)*. Buster results for F(I, 1) = const. are superimposed for curve generation.

With keys F(I,1) = 1., ...8. the following curves are defined.

F(I,1)

= 1. body planform projection span coordinate

2. body planform projection curve vertical ordinate on surface

3. upper crown line, vertical ordinate

4. lower crown line, vertical ordinate

5.
6. local superelliptical exponents for lower half (below planform projection line) of cross section,
   5. at lower crest line,
   6. at planform projection line

7.
8. local superelliptic exponents for upper half (above planform projection line) of cross section
   7. at planform projection line
   8. at upper crest line

<u>Wing fairing to body surface</u>

Independently from the generated location of the wing this may be moved translatory into a new position in 3D space. Thus, it may be adjusted to body crown lines definition, prescribing high -, mid- or low-wing configurations. x- and z- station of the root section twist axis may be corrected, difference to wing generator values defines shift of the whole wing. The wing root section is projected into span direction onto body. Smooth transition from this 3D curve into sections at constant span, along with a trumpet-like root section area of the generated wing, allow for a smooth surface matching between wing and body without surface slope discontinuities.

---

*) F(I, 9) defines the second derivative at the bump crest instead of bump fullness parameter SB in BUSTER (Ref. 1).

Input for wing-body root fairing

| | |
|---|---|
| XDS<br>YDS<br>ZDS | corrected location of the<br>wing root twist axis |
| YROOT | spanstation beyond which no fairing is applied |
| ART<br>BRT<br>ERT<br>FRT | parameters for subroutine FORM<br>(Ref. 1) for a weighted projection,<br>between root section on body and<br>unchanged section at span = YROOT |

## CODE OUTPUT OPTIONS

### Graphic display

One purpose of the described algorithm in the present version E88-A is a graphic display of the configurations created. This allows rapid checking of the possibilities and limitations to the used analytical functions for a broad variety of wing and body shapes.

### Print and plot control parameters

| | |
|---|---|
| IPRINT | extended printout for value 1 |
| IPLOT | = 0 for no plot |
| | = $\pm$ 1 plots one wing (blade) and half of the body |
| | = 2 plots both wings and complete body |
| | < - 1 plots complete body and a number of k = \|IPLOT\| blades (fins) |
| IVIEW | perspective view parameter, not activated in present version |
| PLFAC | $\leq$ 1 plot size reduction factor |
| ANG1,2 | axonometric view rotation angles in degrees |
| | wing and body trajectories plotted: |
| MPL1 | first trajectory on wing between sections |
| MPLD | step to next trajectory |
| MPL2 | last trajectory |

Flow analysis input data

An increasing number of efficient flow analysis codes for both high and low speed regimes, for flows past aircraft and through turbomachinery is developed. Moreover, computational algorithms for design and optimization of such configurations are desirable to help the designer of aerodynamic structure develop cost efficient aircraft and turbomachinery. The variation of geometric parameters of such configurations is an essential goal of optimization procedures. Since the flow computations are time consuming, at least for the high speed regime and/or inclusion of viscous effects, geometry and computational grid definition procedures should be fast and flexible. Two analysis algorithms (3, 4) for isolated wings in the transonic regime have recently been extended to be shock-free wing design tools: they calculate local geometry changes on given wings to provide shock-free flow at given operating conditions (5, 6). These analysis/design codes require wing geometry data specified by two output options of the present generator code.

Analysis codes input generator

| | | |
|---|---|---|
| ISAVE | > 0 | data stored on tape |
| ICODE | 1 | input geometry for finite volume code (3, 5) |
| | 2 | input geometry for finite difference code (4, 6) |

APPLICATIONS

Aircraft wing-fuselage combinations

Realistic aircraft configurations need, of course, account to be taken of all major details of wings, body, engines, and tail. Capability of this code is restricted to wing/body combinations without tails and engines. The example Fig. 1 is a simplified representation of a Gates Learjet aricraft. Four plots are shown, with view angles

| Fig. 1 | ANG 1 | ANG 2 |
|---|---|---|
| a | 90. | 0. |
| b | 0. | 0. |
| c | 22.5 | -40. |
| d | 0. | 90. |

Fig. 1a shows, how the wing sections are displaced in the root area, with the root section projected toward the body. Another aircraft was used to define wing body combinations depicted in Fig. 2: The Lockheed wide body transport aircraft L1011 geometry is used presently for wing design studies, Fig. 2a shows the configuration with the original L1011 planform. In Fig. 2b an analytical modification of the wing root area shows the possibilities of this surface generator: only a few numbers need to be changed to arrive from Fig. 2a in Fig. 2b. The fuselage cross sections show a basicly circular shape, with a smooth transition to a more square shape near the landing gear box and wing root.

<u>Rotors and missiles</u>

Special cases of the body surface are badies of revolution, generated by equal shapes of upper and (minus) lower crown lines and planform projection line. If the single, surface fitted wing is rotated around the x-axis (IPLOT < -1) rather than reflected at the xz-plane (IPLOT = 2), then we obtain a propeller or, with nonlifting symmetrical wing sections, a missile. Fig. 3 illustrates an advanced type turboprop geometry with highly twisted blades. The possibility of section blending along the blade with a root, a main, and a tip section allows a systematic optimization, taking into account the structural requirements, especially at the root section, but also the supercritical flow at the main center portion of the blade, and the supersonic flow in the outer portion of the blade. Consequently, these very different problems will lead to different basic sections: a thick root section sitting on an

area-ruled hub, a supercritical section with weak shock in the midportion of the blade and a thin and sharp supersonic airfoil section at the tip.

## Surface fitted three-dimensional grids

Present version (E88-A) of this geometry definition program does not provide for computational 3D grids to be used in flow analysis algorithms. However, the wing and body shape definition subroutines are designed to establish an arbitrary metric along the surface to be used in various analysis and design codes, which requires continuation of the grid along wing/body into space. Some options for useful 3D space grids will be presented in Ref. (2). In the present version surface grids for body and wing are generated separately only to be used in the graphic display output.

## Transonic wing design

Design methods for supercritical isolated wings with shock-free flow are operational. The two methods (5, 6) using geometry input from the present generator are used presently to study wing improvements of the aircraft elements illustrated in Figures 1 and 2. The root modifications Fig. 2b of course require a wing-body code, but preliminary studies are performed presently to study an upstream extension of an isolated wing near the center plane. Fig. 4 shows the pressure distribution on the wing, with the shape of the sonic surface on the wing. Viscous effects are taken into account by adding a displacement thickness to the wing based on viscous 2D airfoil analysis results. Figure 5 shows a result for a wing with viscous displacement added and a planform derived from the aircraft element Fig. 1. Some sections in magnified scale show the amount of thickness reduction necessary to arrive from an initial configuration with a shocked flow at a shock-free surface modification. The latest version of this design code (6) includes viscous

effects by iterative solution of the inviscid outer flow with boundaries determined by geometry and a three-dimensional boundary layer method.

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FIGURES

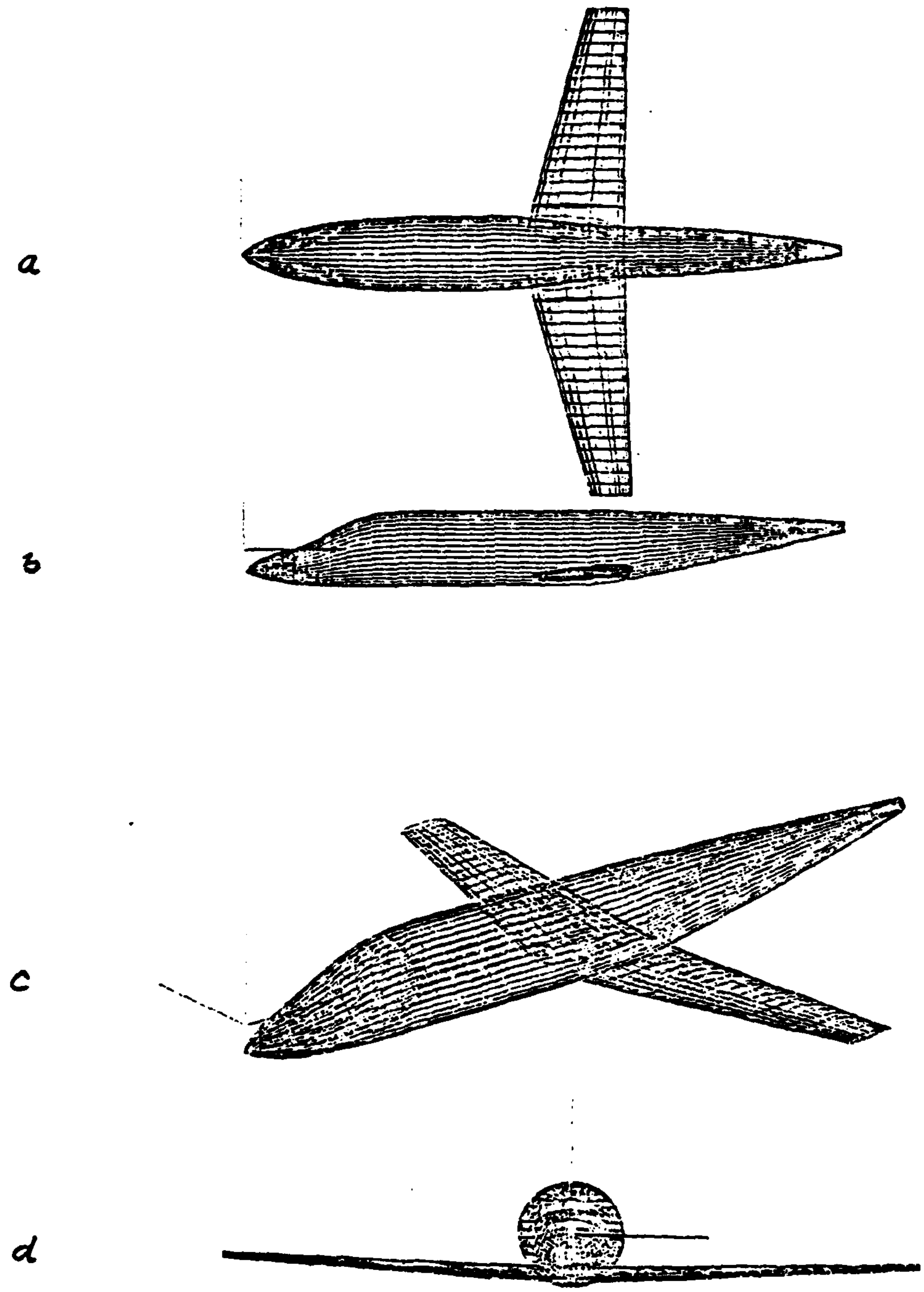



Figure 1. Wing-fuselage combination based on Gates Learjet aircraft.

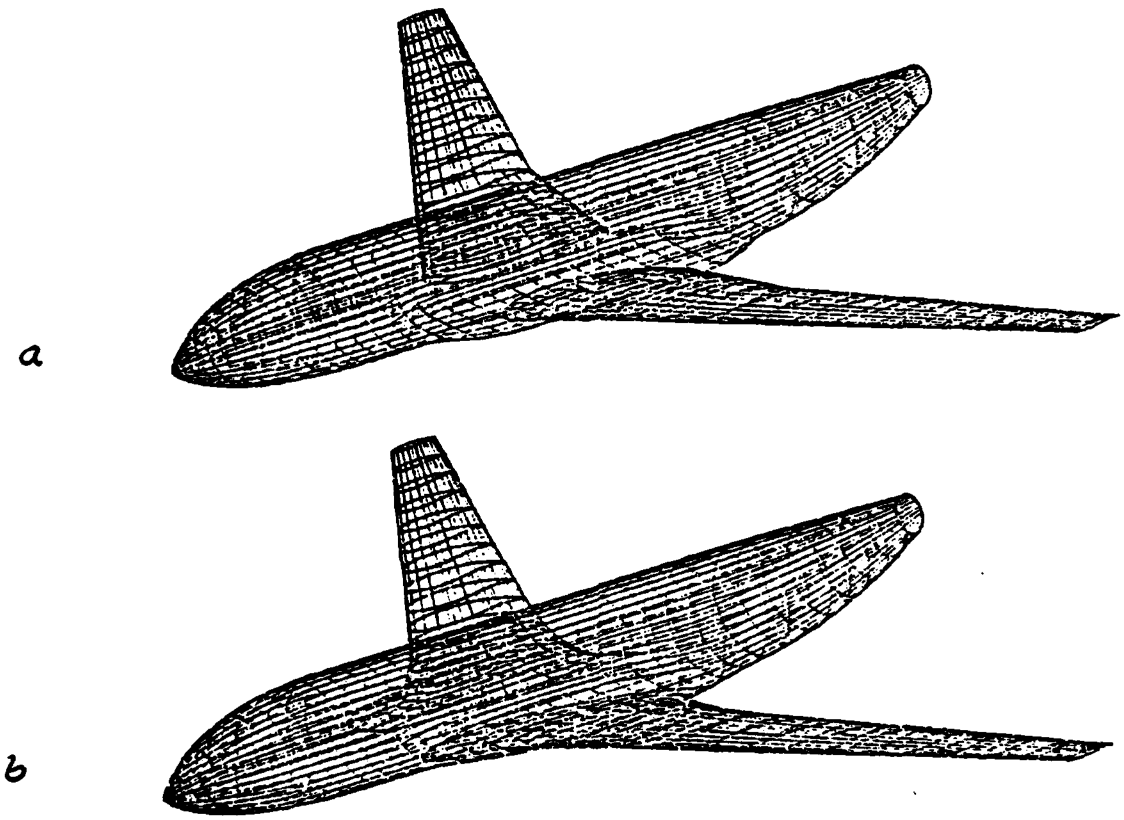



Figure 2. Wing-fuselage combination based on Lockheed 1011 aircraft, wing root modification.

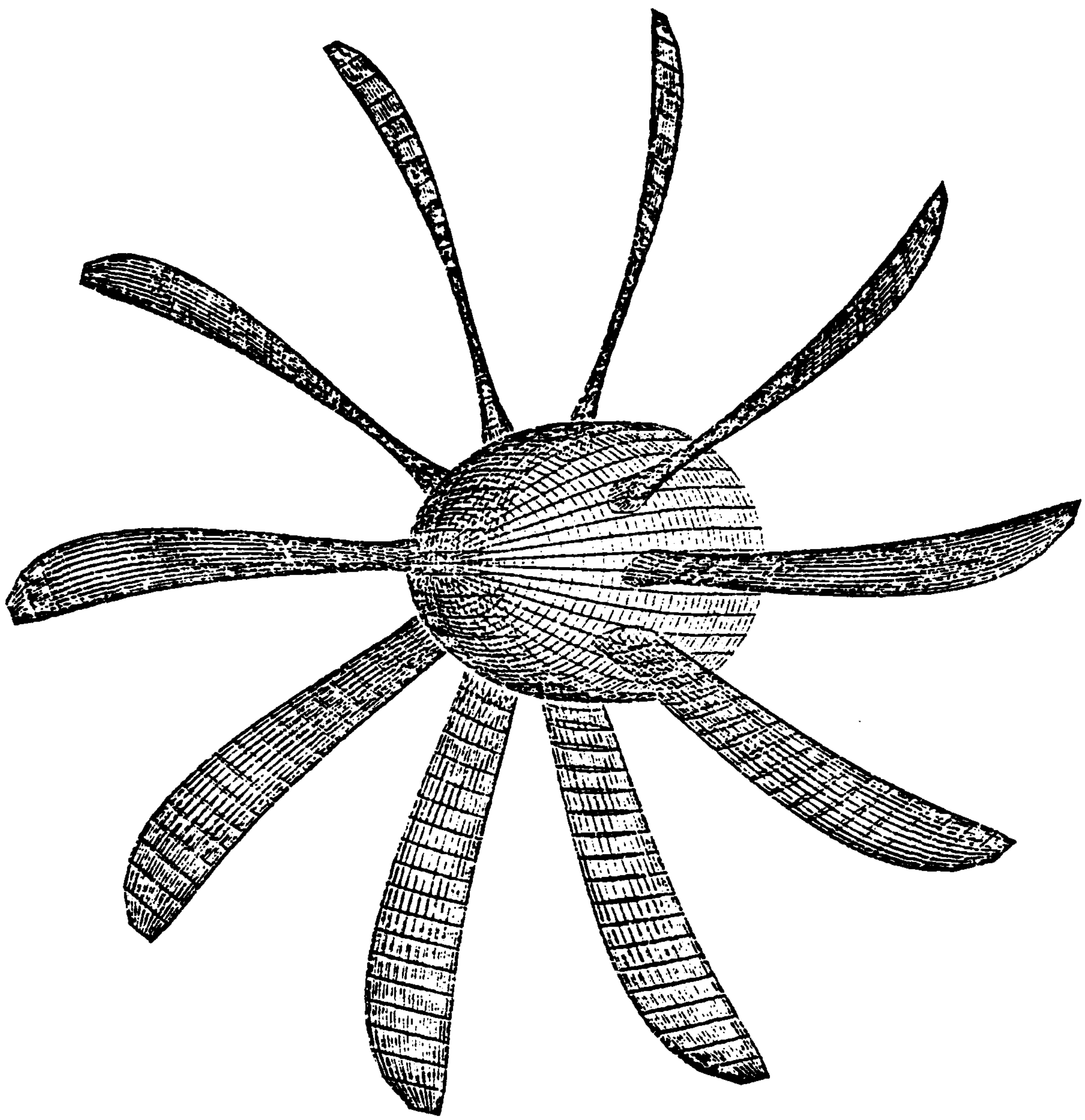


Figure 3. Advanced turboprop geometry.

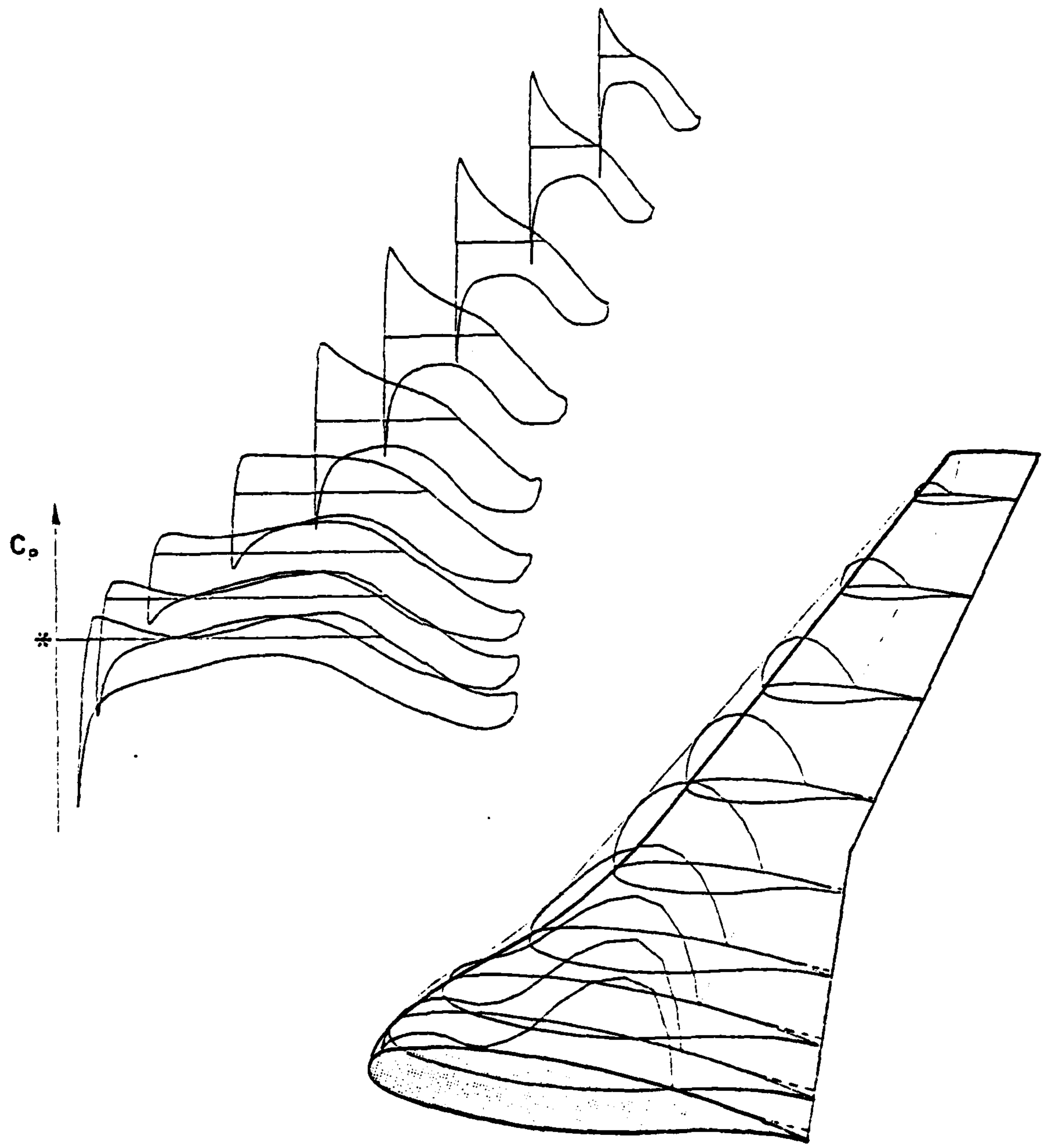



Figure 4. Supercritical shock-free lifting wing, pressure distribution, sonic surface (Mach = 0.8, $C_L$ = 0.5).

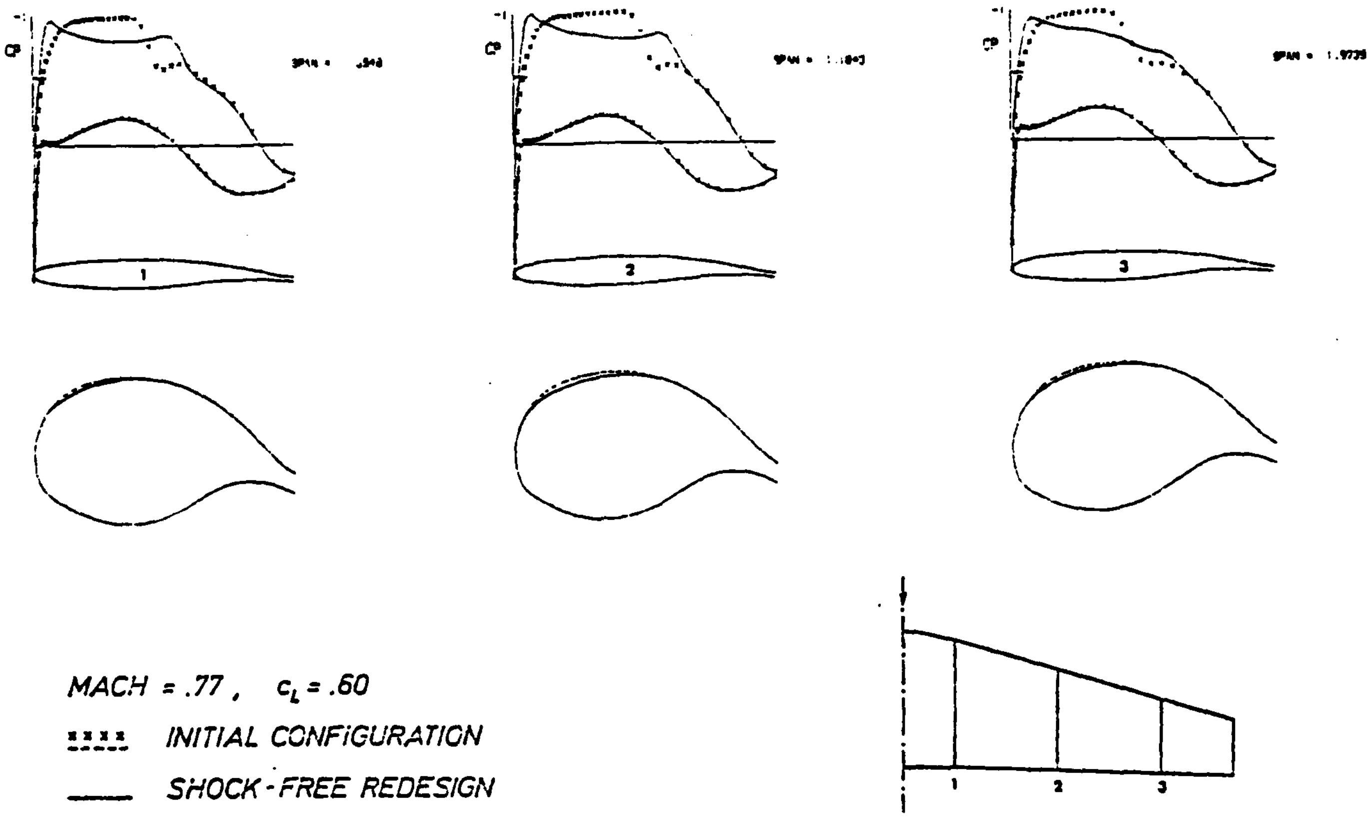
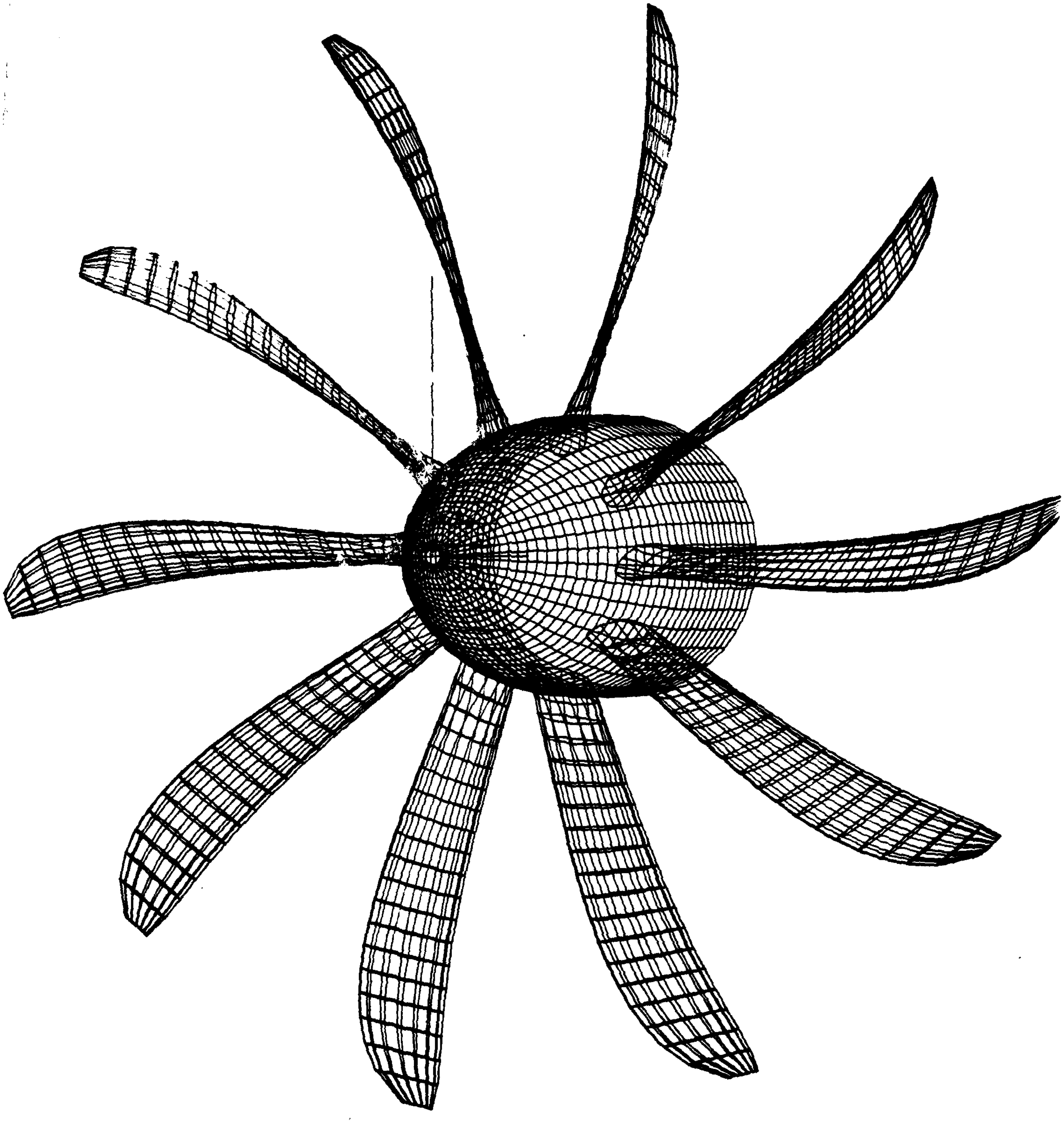



Figure 5. Supercritical lifting wings before and after shock-free redesign.



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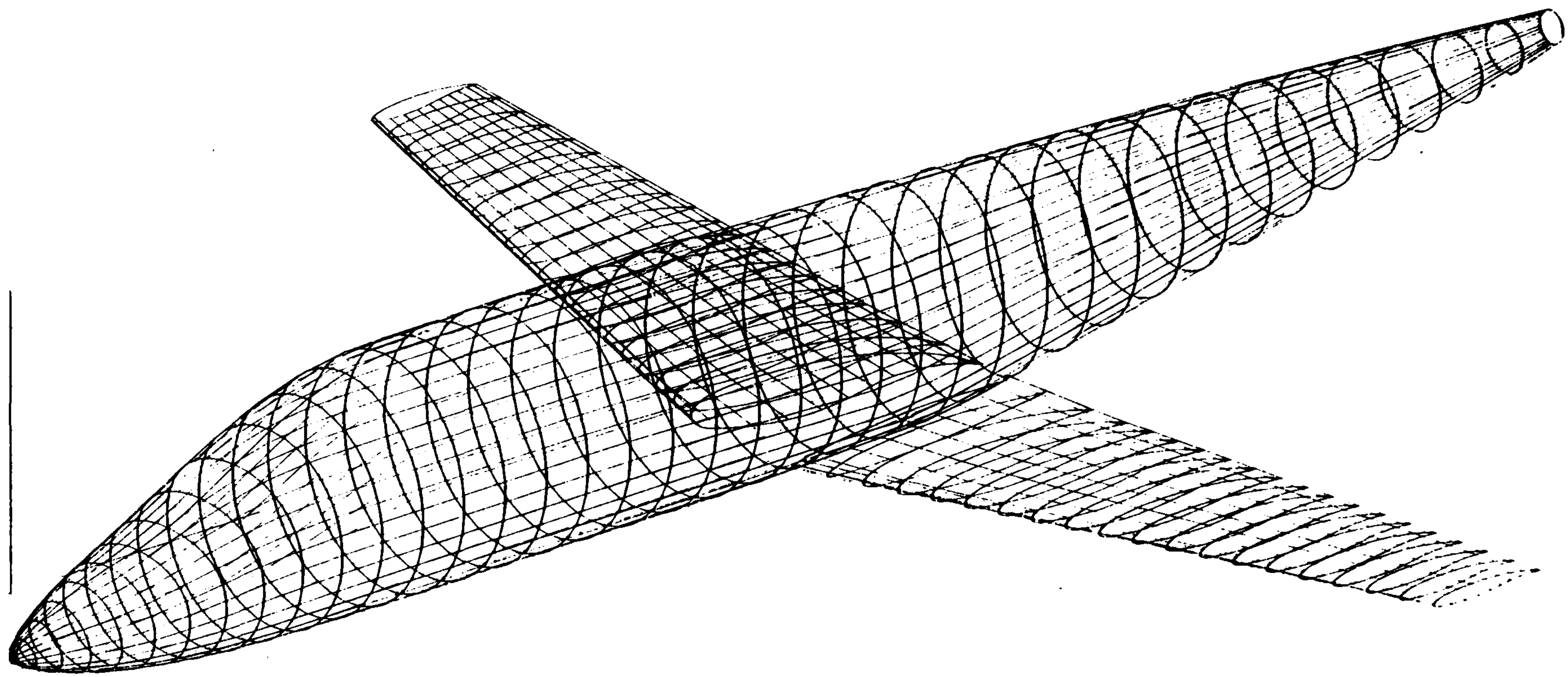

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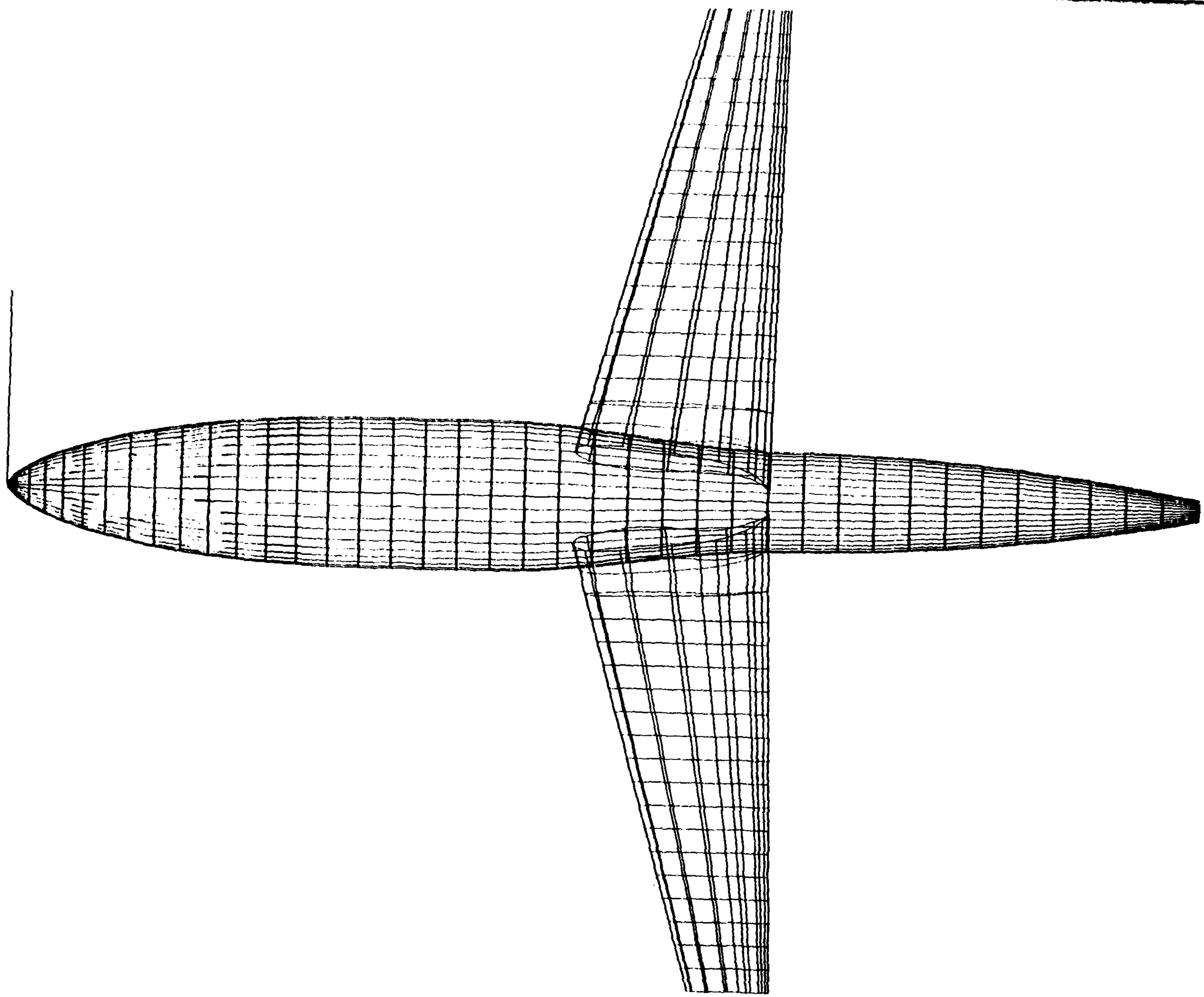

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